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Experimental Study on Electromagnetic Treatment for Reducing Salinity in Groundwater

Asraa Ishneebeesh[1] | Salsabeel Alahrash[1] | Aboalgasem Alakhdar[2]*

[1]Environmental Engineering Department, Faculty of Engineering, Sabratha University, Sabratha, Libya.
[2]Geological Engineering Department, Faculty of Engineering Jadu, Nalut University, Jadu, Libya.

ABSTRACT

Purpose: This study aims to evaluate the effectiveness of electromagnetic treatment using aluminum electrodes in improving the physicochemical properties of highly saline groundwater.

Materials and Methods: An experimental system was designed consisting of a treatment tank equipped with aluminum electrodes and a magnetic field source. A saline water sample with a total dissolved solids concentration of 30,633 ppm was treated under controlled laboratory conditions at 35 V. Several treatment durations (30 minutes, 45 minutes, 1.5 hours, and 3 hours) were tested. Key parameters, including pH, electrical conductivity, total hardness, and concentrations of major ions (Na^+, Ca^{2+}, Mg^{2+}), were measured before and after treatment.

Results: The results showed a gradual improvement in water quality over time. TDS decreased significantly from 30,633 ppm to 20,738 ppm after 3 hours. Electrical conductivity and total hardness also showed notable reductions. Concentrations of sodium, calcium, and magnesium decreased, indicating effective removal of dissolved ions. XRD analysis confirmed the formation of precipitates mainly composed of sodium chloride and calcium sulfate.

Conclusion: Electromagnetic treatment proved to be an effective and environmentally friendly technique for reducing salinity and improving groundwater quality. The method shows strong potential as an alternative water treatment solution, although further optimization is required for large-scale applications.

Keywords: Electromagnetic Treatment, Electrocoagulation, Water Desalination.

Audioabstract:

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*Corresponding author:
Aboalgasem Alakhdar
Email: a.alakhdr@nu.edu.ly

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1. INTRODUCTION

Water resources represent one of the most critical environmental challenges worldwide, particularly in arid and semi-arid regions where freshwater availability is limited. Groundwater is considered one of the primary sources of water for domestic, agricultural, and industrial purposes.[1] In many regions of the world, groundwater constitutes the main source of drinking water and irrigation due to the scarcity of surface water resources and irregular rainfall patterns.[2]

Despite its importance, groundwater quality is increasingly threatened by various forms of contamination including biological, chemical, and physical pollution.[3] Among these, salinization caused by seawater intrusion represents one of the most significant threats to coastal aquifers. When

excessive groundwater pumping occurs, the natural hydraulic balance between freshwater and seawater is disturbed, allowing saline water to move inland and contaminate freshwater aquifers. This process increases the concentration of dissolved salts such as sodium, chloride, calcium, and sulfate ions in groundwater systems.[4]

Libya is considered one of the countries facing increasing challenges related to groundwater salinity. This is mainly attributed to its long coastline along the Mediterranean Sea, in addition to its heavy reliance on groundwater aquifers as a primary source for drinking water and agricultural needs[5]. In many coastal areas, excessive groundwater pumping has led to a disruption of the hydraulic balance between freshwater and seawater, contributing to the inland advancement of the seawater intrusion front, and consequently resulting in the deterioration of groundwater quality.[5]

Despite the presence of the Quaternary-age Gargares formations, which were deposited in marine and coastal environments and are characterized by specific sedimentological properties, these formations have not been sufficient to prevent seawater intrusion, particularly under the increasing hydrological stresses caused by overexploitation. A representative section of these formations, with an approximate thickness of 14 meters, has been described along the coastal zone west of Tripoli.[6]

To address this issue, several water treatment and desalination technologies have been implemented, including reverse osmosis, ion exchange, electrodialysis, and thermal desalination methods[7]. Although these techniques are highly effective, they are often associated with high energy consumption, significant capital and operational costs, and the need for advanced control and operation systems. Therefore, current research efforts are increasingly directed toward developing alternative technologies that are more energy-efficient, cost-effective, and environmentally sustainable.[7]

Electrocoagulation has emerged as a promising technique for water purification. In this process, an electric current is passed through metal electrodes, typically aluminum or iron, producing coagulant species that destabilize dissolved and suspended contaminants, allowing them to aggregate and precipitate out of solution.[8]

In addition to electrocoagulation, magnetic and electromagnetic water treatment technologies have attracted growing scientific interest. These technologies rely on exposing water to magnetic or electromagnetic fields that influence the physicochemical behavior of dissolved ions and water molecules.[9]

Therefore, the objective of this study is to investigate the effectiveness of electromagnetic treatment using aluminum electrodes for improving the physicochemical properties of saline groundwater under controlled laboratory conditions.

2. MATERIALS AND METHODS

2.1 Experimental Setup

The experimental system consists of a treatment tank equipped with aluminum electrodes connected to an electrical power supply. Two magnets were attached to the aluminum electrodes to generate a constant magnetic field within the water (Fig. 1), The experiments were conducted at the Environmental Engineering Laboratory, Faculty of Engineering, Sabratha. The system illustrated in (Fig. 1) was originally designed by Dr. Aboalgasem Alakhdar.

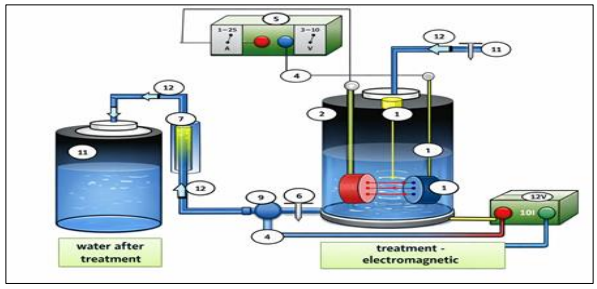

Fig. 1 : Schematic diagram of the electromagnetic water treatment system.

Where the numbers in the (Fig.1) indicate:

1	Aluminum electrodes	6	Valve	10	12V Power Supply
2	Tank	7	Filter	11	Water Inlet
3	Magnet	8	Thermometer	12	Pipes
4	Wires	9	12V Pump	13	Treated Water Tank
5	AC power source				

The experiments were conducted by passing electric current through the electrodes immersed in water while the water was subjected to a magnetic field. During the experiments, several parameters were monitored, including temperature, current intensity, voltage difference, and electrode weight before and after treatment.

2.2 Experimental Procedure

2.2.1 Distilled Water Experiment

The first phase of the study aimed to examine the effect of the electromagnetic field on distilled water. A 4-liter tank was filled with distilled water (Fig. 2), and aluminum electrodes were installed inside the tank. Two magnets were positioned below the electrodes at a distance of approximately 5 cm to create a static magnetic field (Fig. 2).

Fig. 2: Aluminum electrode and magnet configuration in distilled water.

Before starting the experiment, the electrodes were cleaned, dried, and weighed using a sensitive electronic balance. The initial temperature of the water was recorded. The electrodes were then connected to an alternating voltage source (30 V) (Fig. 3), and the system was operated for 30 minutes.

Fig. 3: pH device, AC power supply (30 V).

At the end of the experiment, the final water temperature and electrode weights were measured and recorded (Table 1). This step served as a control experiment to observe any physical or chemical changes in distilled water under electromagnetic influence.

Table 1: Operational variables for distilled water.

Variables	Variable Values
Initial Electrode Weight at the Beginning of the Experiment	I=66.60g II=63.66g
Time	30 min
Water Volume	4L
Initial Temperature at the Start of the Experiment	T_1=25.3°C
Voltage Difference	30V
Current Intensity	0A
Electric Power	0 W
Final Temperature at the End of the Experiment	T_2=25.3°C
Final Electrode Weight at the End of the Experiment	I=66.60g II=63.66g

To verify the operation of the device, an additional step was conducted by adding 1 liter of saline water with a salinity of 30,633 ppm to the distilled water. The experiment was repeated, and temperature changes were recorded every 10 minutes. Observations were made regarding temperature variation, current intensity, and electrode conditions after the experiment.

2.2.2 Treatment of Saline Water (30,633 ppm)

In the third phase, a water sample with a salinity of 30,633 ppm was collected from a coastal well at a depth of approximately 25 meters. Before collecting the sample, the pump was operated for 20 minutes to ensure that the sample represented the actual well water.

Approximately 20 liters of water were collected, and a portion was sent for laboratory analysis to determine its chemical composition and initial parameters such as total dissolved solids and electrical conductivity.

Nine liters of the sample were used in the electromagnetic treatment system. The electrodes were weighed before starting the experiment, and the water temperature was recorded. The system was operated at a voltage of 35 V (Fig. 4).

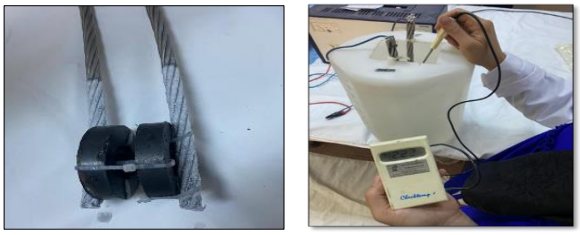

Fig.4: Condition of the electrodes after the experiment.

To investigate the effect of treatment time, experiments were conducted at several durations, including 30 minutes, 45 minutes, 1.5 hours (Table 2), and 3 hours. During each experiment, water temperature was recorded periodically, and observations were documented

Table 2: Experimental conditions after (an hour and a half).

Variables	Variable values
Electrode weight (initial)	I=66.15g--II=66.33g
Time	One and a half hour
Water quantity	6.5L
Initial temperature	23.2°C
Voltage difference	35V
Current intensity	19A
Final temperature.	93.7°C
Final electrode weight	I=68.43g--II=68.07g

After each treatment period, the water was filtered to remove precipitates formed during the process (Fig. 5), Samples of the treated water were collected and sent to the laboratory for chemical analysis.

Fig. 5: The precipitate after drying in the water filtration.

2.3 Chemical and Physical Analysis

Several chemical and physical analyses were conducted to evaluate the effectiveness of electromagnetic treatment. These analyses included pH, electrical conductivity (EC), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}).

Chemical and physical analyses were conducted on electromagnetically treated water samples to evaluate the efficiency of the treatment process.

2.3.1 pH Measurement

Water samples were collected in polyethylene bottles without preservatives and analyzed within 24 hours. The pH was measured using a calibrated pH meter with standard buffer solutions (pH 4, 7, and 10). The reading was recorded once it stabilized. Measurement accuracy was calculated using the following equation:

$$Accuracy\ \% = ((\mu - x) \times 100) / \mu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

x = device reading of the standard solution

μ = reference value of the standard solution.[10]

2.3.2 Electrical Conductivity

Samples were collected in glass or polyethylene bottles and stored at 4°C until analysis. Electrical conductivity was measured using a calibrated conductivity meter, and the reading was recorded after stabilization.

Measurement accuracy was calculated using:

$$Accuracy\ \% = ((\mu - x) \times 100) / \mu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: x = device reading of the reference conductivity solution

μ = reference conductivity value.[10]

2.3.3 Total Hardness Determination

Total hardness was determined using the EDTA titration method. A 10 mL water sample was titrated with EDTA in the presence of pH 10 buffer and Eriochrome Black T indicator until the color changed from purple to light blue. The titration was repeated three times to ensure accuracy.[10]

2.3.4 Calcium Determination

Calcium was determined by EDTA titration at pH 12 using Murex ide indicator until the color changed from light pink to purple. Calcium hardness was calculated using:

Calcium Hardness (mg/L as $CaCO_3$)

$$(1000 \times 101.1 \times M \times V) / Sample\ Volume \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Calcium ion concentration was calculated as:

$Ca^{2+} = (1000 \times 40 \times M \times V) / Sample\ Volume$……..(4)

Where:

V = volume of EDTA used in titration (mL)
M = molarity of EDTA solution
101.1 g/mol = molar mass of $CaCO_3$
40 g/mol = molar mass of Ca^{2+}.[10]

2.3.5 Magnesium Determination

Magnesium concentration was calculated from the difference between total hardness and calcium Mg^{2+} titration results using the following equation:

$(1000 \times 24.312 \times M \times (V_2 - V_1) / Sample\ Volume$... (5)

Where:

V_1 = EDTA vol. (Total Hardness) mL

V_2 = EDTA vol. for Ca titration (mL)

M = molarity of EDTA solution

24.312 g/mol = molar mass of Mg^{2+}.[10]

2.3.6 Sodium Determination

Sodium concentration was determined using Flame Emission Spectrometry. Standard sodium solutions were prepared to construct a calibration curve, and the sodium concentration in water samples was determined accordingly.[10]

3. RESULTS AND DISCUSSION

3.1 Chemical and Physical Analysis Results of the Original Water 30633 PPM:

A high-intensity electromagnetic treatment experiment was conducted on a saline water sample with a high concentration of total dissolved solids (TDS), reaching 30,633 ppm, as shown in Table (Table 3). The aim was to evaluate the gradual changes in the chemical and physical properties of the water under the influence of both electric and magnetic fields, and to assess the efficiency of this technique in improving water quality over different time intervals totaling three hours. The following section provides an interpretation of the results:

Table 3: Results obtained from the electromagnetic treatment of a saline water sample with a concentration of 30,633 ppm (TDS).

Parameters	Original sample	Electromagnetic treatment after 30 minutes	Electromagnetic treatment after 45 minutes	After one and a half hour	After 3hours
pH	6.7	6.67	6.8	6.83	6.867
EC (µs/cm)	47133.33	47817.33	47107	34416.33	31923.3
TDS (ppm)	30633.3	31059.23	30543	22350.3	20738.3
TH (mg/L)	6093	6213	6507	4911.33	3789.67
Na (mg/L)	9998	9762.33	9771	9313.33	8203.33
Ca (mg/L)	535.63	463	480	424.87	417.87
Mg (mg/L)	1160.13	1215.367	1182	923.43	499.33
Initial Electrode Weight at the Start of the Experiment				**Wi1**=64.72g- **Wi2**=64.03g	
Final Electrode Weight at the End of the Experiment				**Wf1**=69.99g- **Wf2**=70.92g	

3.1.1 PH (Hydrogen Ion Concentration):

At the outset of the experiment, the pH value was recorded at 6.7, which is close to neutral. Over time, this value gradually increased to 6.867 after three hours. This slight change in pH indicates a balance in the chemical reactions occurring within the system, with no significant shift toward acidity or alkalinity. This can be attributed to a relative equilibrium between the reaction products and the consumption of essential ions, such as H^+ and OH^-, in the medium. (Fig. 6).

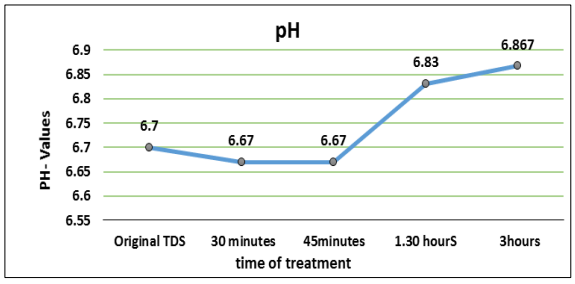

Fig.6: Effect of treatment time on PH.

3.1.2 Electrical Conductivity (EC):

The electrical conductivity exhibited a nonlinear behavior; it increased slightly after the

first 30 minutes (47817.33 µS/cm), then gradually decreased to 31923.3 µS/cm after 3 hours. This gradual decrease is associated with a reduction in the concentration of dissolved solids from 30633.3 ppm to 20738.3 ppm (Table 3), reflecting the system's efficiency in removing a significant portion of the dissolved ions, either through precipitation at the electrodes or through electrochemical reactions within the aqueous medium. (Fig. 7).

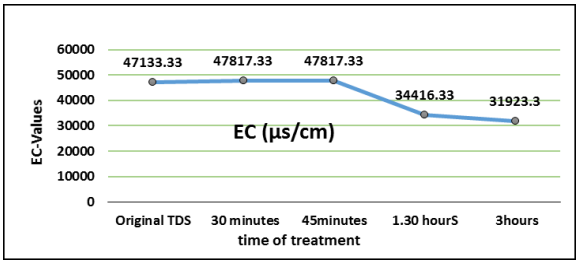

Fig. 7: Effect of treatment time on electrical Conductivity.

3.1.3 Total Hardness (TH):

Regarding total hardness (TH), a noticeable decrease was observed, from 6093 mg/L to 3789.67 mg/L, indicating a reduction in the concentration of calcium and magnesium ions, which are primarily responsible for hardness. It was observed that the calcium concentration decreased from 535.63 mg/L to 417.87 mg/L, while magnesium decreased from 1160.13 mg/L to 499.33 mg/L (Table 3). This significant reduction can be attributed to the precipitation of these ions as carbonates or sulfates, driven by the effects of the electric potential and magnetic field.

3.1.4 Sodium (Na^+):

The analysis results showed a gradual decrease in the concentration of sodium ions, from 9998 mg/L in the original sample to 8203.33 mg/L after three hours of electromagnetic treatment. This decline indicates the effectiveness of the treatment in reducing the sodium concentration in the water, despite sodium being a monovalent ion that is highly soluble and generally more resistant to precipitation. This reduction may be due to the association of sodium with other negative ions (such as carbonate or sulfate), forming salts that gradually precipitate or are adsorbed onto the surface of the metal electrodes. Additionally, the increased temperature resulting from the electrical current may have played a role in accelerating these reactions. (Fig. 8).

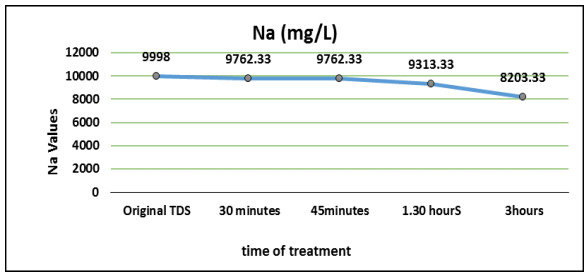

Fig.8: Effect of treatment time on Na^+.

3.1.5 Calcium (Ca^{2+}):

The concentration of calcium decreased from 535.63 mg/L to 417.87 mg/L, indicating a notable reduction likely due to precipitation. As a divalent ion, calcium plays a significant role in water hardness and readily reacts with bicarbonate and sulfate ions to form insoluble compounds such as calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$), particularly at elevated temperatures The application of an electromagnetic field is believed to accelerate these chemical reactions, thereby reducing the solubility of calcium and promoting its removal from the aqueous phase. This process resulted in the observed decline in calcium concentration, as illustrated in (Fig. 9).

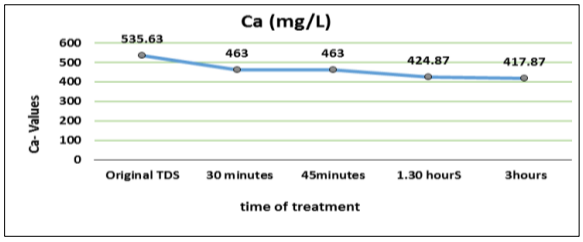

Fig.9: Effect of treatment time on Ca^{2+}.

3.1.6 Magnesium (Mg^{2+}):

Magnesium exhibited a distinct behavior during the treatment process. Initially, its concentration increased slightly from 1160.13 mg/L to 1215.37 mg/L within the first 30 minutes, possibly due to the release of magnesium from dissolved compounds or from the surfaces of the treatment system components, such as pipes and electrodes.

Subsequently, a sharp decline was observed, reaching 499.33 mg/L after three hours of treatment. This significant reduction indicates the effectiveness of the electromagnetic field in

promoting the precipitation of magnesium in the form of insoluble compounds such as magnesium carbonate ($MgCO_3$) or magnesium hydroxide ($Mg(OH)_2$).

These findings highlight the system's capability to reduce magnesium concentrations effectively and enhance water quality through electromagnetic treatment. The trend is illustrated in (Fig.10).

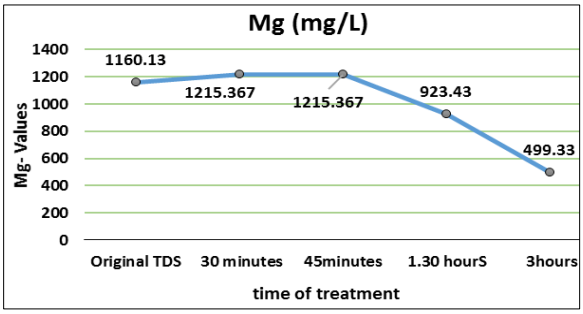

Fig.10 : Effect of treatment time on(Mg²(.

3.1.7 Total Dissolved Solids (TDS):

The results of the electromagnetic treatment experiment on saline water with an initial total dissolved solids (TDS) concentration of 30,633.3 ppm revealed a gradual reduction in TDS values over time, indicating the treatment's effectiveness in lowering the concentration of dissolved salts.

At the outset, the TDS level reflected a high degree of salinity. After 30 minutes of treatment, a slight increase in TDS was observed, reaching 31,059.23 ppm (Table 3). This temporary rise may be attributed to the release of additional dissolved ions due to early electrochemical interactions, such as desorption from surfaces or ion exchange triggered by electromagnetic stimulation and localized heating.

As treatment progressed, the TDS began to decline. After 45 minutes, it decreased to 30,543 ppm, suggesting the beginning of ion removal or precipitation processes. A more pronounced reduction was observed after 90 minutes, with TDS levels dropping to 22,350.3 ppm (Table 3). This significant decrease reflects the role of metal electrodes and the electromagnetic field in promoting the aggregation or precipitation of dissolved ions, thus enhancing water quality.

These findings confirm the efficiency of the treatment in reducing salinity through gradual removal of soluble components.

At the end of the experiment, after three hours of continuous electromagnetic treatment, the total dissolved solids (TDS) value decreased to 20,738.3 ppm, marking a significant reduction compared to the initial concentration of 30,633.3 ppm. This substantial decline confirms the positive impact of electromagnetic treatment in reducing salinity and improving the quality of brackish water.

The marked decrease in TDS is attributed to several concurrent mechanisms, including the precipitation of dissolved ions and their adsorption onto metal electrodes. These processes were evidently enhanced by the electromagnetic field and the thermal and electrochemical conditions created during the treatment.

Based on these findings, electromagnetic treatment can be considered a promising and efficient technology for reducing the salinity of saline water. Its ability to lower the concentration of dissolved salts makes it a viable option for a range of applications, particularly agricultural irrigation and industrial processes that require water of lower salinity.

To fully realize the potential of this technology, further research is recommended particularly in large-scale and long-term applications to optimize operational parameters and assess the sustainability and cost-effectiveness of electromagnetic water treatment systems

3.2 Change in the Weight of Electrodes:

The results of the electrode weight measurements before and after electromagnetic treatment of saline water, as illustrated in Figure 4.13, revealed a notable increase in electrode mass. The initial weights were Wi_1 = 64.72 g for the first electrode and Wi_2 = 64.03 g for the second. Following the three-hour treatment, the final weights rose to Wf_1 = 69.99 g and Wf_2 = 70.92 g, representing increases of 5.27 g and 6.89 g, respectively (Fig.11)

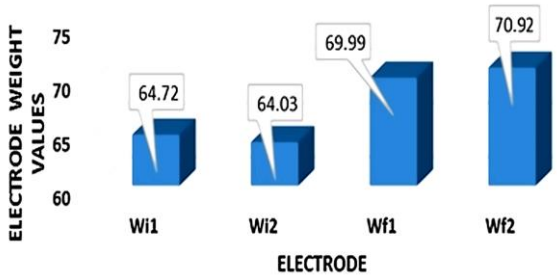

Fig .11: Effect of treatment time on)$^{+}$Ca²(.

This significant weight gain indicates the accumulation of materials on the electrode surfaces. The observed increase is likely due to precipitation and adsorption processes, where dissolved ions from the saline water—such as sodium, calcium, and other minerals—interacted with the electromagnetic field and settled onto the electrodes. These processes are consistent with earlier findings in the experiment, where reductions in ion concentrations were observed in the treated water.

The accumulation of solid residues on the electrodes not only reflects the effectiveness of the treatment in removing dissolved substances, but also highlights the active role of the electrodes in the treatment mechanism through electrochemical deposition and ionic bonding.

These findings suggest that electromagnetic water treatment not only alters water chemistry but also facilitates the physical removal of salts via electrode surface interactions. Optimizing the choice of electrode material, surface area, and treatment duration could further enhance efficiency, making this technique more effective and applicable for larger-scale water treatment systems.

Results of the Precipitate Analysis Obtained from the Electromagnetic Treatment Process:

X-ray diffraction (XRD) analysis of the precipitate formed during the electromagnetic treatment (EMR) of high-salinity water (TDS = 30,633.3 ppm) revealed the presence of two dominant crystalline compounds: 66% sodium chloride (NaCl) and 34% calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), (Table 4).

These findings confirm the efficacy of the electromagnetic treatment in altering the chemical composition of saline water by inducing the precipitation of dissolved salts. The formation of these specific compounds indicates that sodium, chloride, and calcium ions being among the major contributors to water salinity and hardness were successfully removed from the solution through crystallization mechanisms facilitated by the treatment process.

Table 4: X-ray results for the precipitate formed during EM treatment.

Ref. Code	Chemical Formula	Quantitative %
01-077-2064	NaCl	66
00-036-0432	$CaSO_4 \cdot 2\ H_2O$	34

3.3 Interpretation of XRD Precipitate Composition:

The high percentage of sodium chloride (NaCl) Figure 4.14 identified in the precipitate highlights the capability of electromagnetic treatment to influence ion behavior in solution. The electromagnetic field alters the spatial arrangement of molecules and ions, enhancing their interaction and promoting the crystallization of soluble salts. This process is reflected in the observed decrease in sodium and chloride concentrations in the treated water, as confirmed by post-treatment chemical analyses further validating the efficiency of this method in salt removal.

The presence of a significant amount of calcium sulfate dihydrate (gypsum) in the precipitate indicates that calcium ions reacted with sulfate ions under the influence of the electromagnetic field, resulting in the formation of a low-solubility compound. This compound readily precipitates out of the solution, contributing to a reduction in water hardness. Since calcium and sulfate are primary contributors to water hardness, their removal directly enhances water quality.

The accumulation of solid compounds on the electrodes, as demonstrated by the increase in electrode weight after treatment, further supports the XRD findings. This suggests that the reactions are not confined to the solution alone, but also involve the electrode surfaces, which act as catalysts for precipitation and crystallization processes.

Based on these results, it can be concluded that electromagnetic treatment is effective in reducing the concentration of dissolved salts by promoting accelerated precipitation. This is evident from the composition of the precipitate formed during the process. Moreover, the technology enables the removal of harmful components such as calcium, chloride, and sodium without the need for chemical additives, offering a promising environmental and economic solution for saltwater treatment.

4. CONCLUSION

In conclusion, the results of this study demonstrate that electromagnetic treatment using aluminum electrodes is an effective method for improving the physicochemical properties of saline groundwater. The experimental findings revealed a significant reduction in total dissolved solids, electrical conductivity, total hardness, and concentrations of major ions such as sodium, calcium, and magnesium over the treatment period. These improvements can be attributed to the combined effects of electrocoagulation and the applied magnetic field, which enhanced ion aggregation, precipitation, and adsorption onto electrode surfaces.

The gradual decrease in salinity and hardness indicates the potential of this technique as a viable alternative to conventional desalination methods, particularly in regions suffering from water scarcity and high salinity levels, such as coastal areas in Libya. Furthermore, the formation of precipitates confirmed by XRD analysis supports the effectiveness of the process in removing dissolved salts through crystallization mechanisms without the addition of chemical reagents.

Despite these promising results, the accumulation of deposits on electrode surfaces, which may affect long-term performance. Therefore, further research is recommended to optimize operational parameters such as voltage, treatment time, and electrode configuration, as well as to evaluate the scalability and economic feasibility of the system for large-scale applications.

Overall, electromagnetic water treatment presents an environmentally friendly and potentially cost-effective solution for saline water remediation, with promising applications in agriculture, industry, and water resource management.

5. ACKNOWLEDGEMENT

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